INPUTS and CONSTANTS

American Tunnel #1 Bulkhead design check: 2/8/2015

Tunnel Height (h_t)	13	ft
Tunnel Width (w_t)	13	ft
Bulkhead Height (h_b)	13	ft
Bulkhead Width (w_b)	13	ft
Design water head (H)	1550	ft
Bulkhead Trial Thickness (L_T)	25	ft
Water density(γ_w)	62.4	pcf
Overburden rock density (γ_r)	165	pcf
Concrete Density (γ_c)	151	pcf
Concrete Compressive Strength (f_c)	3,000	psi
Acceptable bulkhead pressure gradient (p_{ag})	41	psi/ft
Bulkhead depth below surface (B_w)	2130	ft
Slope Angle of Topography (β)	15.5	
Accoustical velocity of water (c')	4,748	ft/s @50°F
Peak Ground Acceleration (PGA)	0.087	g
Gravity Acceleration (g)	32.2	ft/sec^2
Seed & Idriss Constant (SI)	1.8044	(ft/sec)/g From Seed and Idriss
Seismic Design Handbook Constant (SDH)	2	(ft/sec)/g From Seismic Design
Beam Unit Width (b)	1	ft
Inby Line-of-Site Water Distance (S_{ls})	2486	ft
Rebar Yield Strength (f_y)	60,000	psi
Minimum Rebar Cover (m_c)	3.5	in
Rock Cover Factor of Safety (F_{RC})	1.1	Range 1.1-1.3 (Based on Bergh-C
Fluid Static Load Factor (ϕ_{fs})	1.4	
Concrete Flexural Strength Reduction Factor (ϕ_{pc})	0.55	
Earthquake Static Fluid Load Acceleration Factor (ϕ_{fe})	1.05	
Earthquake Impounded Fluid Load Acceleration Factor (ϕ_{ea})	1.40	
Reinforced Concrete Flexural Strength Reduction Factor (ϕ_{rc})	0.90	
Rebar Flexural Strenth Reduction Factor (ϕ_{rt})	0.90	

1983
Handbook (pg55)

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Hydrofrac

Inputs:

Design water head (H)	1550 ft
Water density(γ_w)	62.4 pcf
Overburden rock density (γ_r)	165 pcf
Acceptable bulkhead pressure gradient (p_{ag})	41 psi/ft
Bulkhead depth below surface (B_w)	2130 ft
Rock Cover Factor of Safety (F_{RC})	1.1
Slope Angle of Topography (β)	15.5 degrees

Calculations:

Maximum Hydraulic Pressure Head (p)	$p = H\gamma_w/144 =$	671.7 psi
Minimum Rock Cover Required (Z) (Able Method)	$Z = 144p/2\gamma_r =$	293.1 ft
Minimum Rock Cover Required (Z) (Norwegian Tunnel Method)	$Z = H\gamma_w F/\gamma_r \cos\beta =$	669.1 ft
Minimum contact grout pressure (σ_{mingp})	$\sigma_{mingp} = B_w\ \gamma_w/144 =$	923.0 psi
Maximum contact grout pressure (σ_{mingp})	$\sigma_{maxgp} = 2B_w\ \gamma_r/144 =$	4881.3 psi
Maximum contact grout pressure (σ_{mingp})	$\sigma_{maxgp} = 2B_w\ \gamma_r \cos\beta/144F_{RC} =$	2138.1 psi
Required bulkhead thickness for pressure gradient (L_{hp})	$L_{hp} = p/p_{ag} =$	16.4 ft

Water Hammer

Approach based on "Permanent Sealing of Tunnels to Retain Tail

Inputs:

Change values on Input Tab

Accoustical velocity of water (c')	4,748	ft/s @50°F	
Peak Ground Acceleration (PGA)	0.087	g	
Water Density (γ_w)	62.4	pcf	
Gravity Acceleration (g)	32.2	ft/sec^2	
Earthquake Static Fluid Load Acceleration Factor (ϕ_{fe})	1.05		
Seed & Idriss Constant (SI)	1.8044	(ft/sec)/g	From Seed and Idriss 1983
Seismic Design Handbook Constant (SDH)	2	(ft/sec)/g	From Seismic Design Handbo

Calculation:

Max Earthquake Acceleration (α)	α = PGA*g =	2.8014	ft/sec^2	
Max Velocity SI (v_{max})	v_{max} = SI*PGA =	0.15698	ft/s	Seed and Idriss
Max Velocity SI (v_{max})	v_{max} = SDH*PGA =	0.174	ft/s	Seismic Design Ha
Water Hammer Pressure (P_H)	$P_H = c'*v_{max}*\gamma_w$ =	51,552	lb	Used SDH
Factored Water Hammer Pressure (P'_H)	$P'_H = P_H*\phi_{fe}$ =	54,129	lb	

ings or Acid Rock Drainage", Lang, 1999.

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Punching Shear Design

Inputs: *Change values on Input Tab*

Concrete Compressive Strength (f_c)	3,000	psi
Bulkhead Height (h_b)	13	ft
Bulkhead Width (w_b)	13	ft
Design Head (H)	1550	ft
Water Density (γ_w)	62.4	pcf
Fluid Static Load Factor (ϕ_{fs})	1.4	
Factored Water Hammer Pressure (P'_H)	54,129	lb (Calculated from Water Hammer Tab)

Calculations:

Concrete Shear Strength (f_{cs})	$f_{cs} = 2*f_c^{1/2}=$	109.5	psi
Static Fluid Load on Bulkhead Face (F_s)	$F_s = H*\gamma_w*h_b*w_b=$	16,345,680	lb
Factored Static Fluid Load on Bulkhead (F_s')	$F_s' = F_s*\phi_{fs} =$	22,883,952	lb
Length of Bulkhead Required for Shear (L_s)	$L_s = F_s'/(2*(h_b+w_b)*f_{cs}*144)$	27.90	ft

Earthquake Consideration (Water Hammer):

Length of Bulkhead Required (L_s)	$L_s = (F_s'+P'_{H})/(2*(h_b+w_b)*f_{cs}*144)$	27.96	ft

Plain Concrete Deep Beam Bending Stress

Inputs:

	Change values on Input Tab		*Change values on Input Tab*
Concrete Compressive Strength (f_c)	3,000 psi	Peak Ground Acceleration (PGA)	0.087 g
Bulkhead Height (h_b)	13 ft	Fluid Static Load Factor (ϕ_{fs})	1.4
Bulkhead Width (w_b)	13 ft	Concrete Flexural Strength Reduction Factor (ϕ_{pc})	0.55
Tunnel Height (h_t)	13 ft	Earthquake Static Fluid Load Acceleration Factor (ϕ_{fe})	1.05
Tunnel Width (w_t)	13 ft	Earthquake Impounded Fluid Load Acceleration Factor (ϕ_{ea})	1.40
Design Head (H)	1550 ft	Beam Unit Width (b)	1 ft
Inby Line-of-Site Water Distance (S_{ls})	2486 ft	Static Fluid Load on Bulkhead Face (F_s)	16,345,680 lb (Calculated from Punching Shea
Water Density (γ_w)	62.4 pcf	Factored Static Fluid Load On Bulkhead Face (F_s')	22,883,952 lb (Calculated from Punching Shea
Concrete Density (γ_c)	151 pcf	Factored Water Hammer Pressure (P'_H)	54,129 lb (Calculated from Water Hamme
Bulkhead Trial Thickness (L_T)	25 ft		

Calculations:

Deep Beam Verification	w_b/L_t =	0.5	Deep Beam
Uniform Static Fluid Load on Face (f'_s)	$f'_s = F'_s/(h_b*w_b)$ =	135,408 psf	
Maximum Nominal Bending Moment (M_n)	$M_n = f'_s*w_b^2/8$ =	2,860,494 ft-lb	(f'_s load per unit length w/ 1ft beam width)
Factored Nominal Bending Moment (M'_u)	$M'_u = M_n/\phi_{pc}$ =	5,200,898 ft-lb	
Concrete Flexural (tensile) Design Stress (f_{cl})	$f_{cl} = 3*f_c^{1/2}$ =	164.3 psi	
Plain Concrete Beam Bulkhead Length (L_{st})	$L_{st} = (6*M'_u/b*f_{cl})^{1/2}$ =	36.3 ft	

Considering Earthquake (Water Hammer):

Factored Earthquake Load on Face (U'_α)	$U'_\alpha = F'_s+P'_H$ =	22,938,081 lb	
Uniform Static Fluid Load on Face (u'_s)	$u'_s = U'_s/(h_b*w_b)$ =	135,728 psf	
Maximum Nominal Bending Moment (M_n)	$M_n = u'_s*w_b^2/8$ =	2,867,260 ft-lb	(u'_s load per unit length w/ 1ft beam width)
Factored Nominal Bending Moment (M'_u)	$M'_u = M_n/\phi_{pc}$ =	5,213,200 ft-lb	
Concrete Flexural (tensile) Design Stress (f_{cl})	$f_{cl} = 3*f_c^{1/2}$ =	164.3 psi	
Plain Concrete Beam Bulkhead Length (L_{st})	$L_{st} = (6*M_u/b*f_{cl})^{1/2}$ =	36.4 ft	

Considering Earthquake (Abel Method):

Factored Earthquake Accelerated Static Fluid Load (E_{fe})	$E_{fe} = F_s*\phi_{fe}$ =	17,162,964 lb	
Factored Earthquake Accelerated Line-of-Sight Fluid Load (E_{fm})	$E_{fm} = S_{ls}*\gamma_w*h_t*w_t*PGA*\phi_{ea}$ =	3,193,153 lb	
Factored Earthquake Bulkhead Load (E_{bm})	$E_{bm} = L_{st}*\gamma_c*h_b*w_b*PGA*\phi_{ea}$ =	77,705.36 lb	
Factored Earthquake Load on Face (U'_α)	$U'_\alpha = E_{fe}+E_{fm}+E_{bm}$ =	20,433,822 lb	
Uniform Static Fluid Load on Face (u'_s)	$u'_s = U'_s/(h_b*w_b)$ =	120,910 psf	
Maximum Nominal Bending Moment (M_n)	$M_n = u'_s*w_b^2/8$ =	2,554,228 ft-lb	(u'_s load per unit length w/ 1ft beam width)
Factored Nominal Bending Moment (M'_u)	$M'_u = M_n/\phi_{pc}$ =	4,644,050 ft-lb	
Concrete Flexural (tensile) Design Stress (f_{cl})	$f_{cl} = 3*f_c^{1/2}$ =	164.3 psi	
Plain Concrete Beam Bulkhead Length (L_{st})	$L_{st} = (6*M_u/b*f_{cl})^{1/2}$ =	34.3 ft	

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Reinforced Concrete Deep Beam Bending Design:

Inputs: *Change values on Input Tab*

Reinforced Concrete Flexural Strength Reduction Factor (ϕ_{rc})	0.90	
Rebar Flexural Strenth Reduction Factor (ϕ_{rt})	0.90	
Concrete Compressive Strength (f_c)	3,000	psi
Beam Unit Width (b)	1	ft
Rebar Yield Strength (f_y)	60,000	psi
Maximum Nominal Bending Moment (M_n)	2,867,260	ft-lb (Plain Concrete Deep Be
Bulkhead Trial Thickness (L_T)	25	ft
Minimum Rebar Cover (m_c)	3.5	in

Calculations:

Compressive Force (C)	$C = \phi_{rc}*f_c*b*a =$	32,400	a (psi)
Tensile Force (T)	$T = A_s*f_y =$	60,000	A_s (psi)
Minimum Concrete Depth to Balance Rebar (a)	a =	1.852	A_s (psi)
Factored Bending Moment (M'$_u$)	$M'_u = M_n/\phi_{rt} =$	3,185,845	ft-lb
Factored Bending Moment (M'$_u$)	$M'_u = M_n/\phi_{rt} =$	38,230,136	in-lb
Maximum Rebar Cover (d)	$d = 12*L_T-m_c =$	296.5	in
$C_1A_s^2-C_2A_sd+M'_u = 0$			
	$C_1 = f_y*a/2 =$	55,556	
	$C_2 = f_y*d =$	-17,790,000	
	$C_3 = M'_u =$	38,230,136	
Area of Steel Required (A_s)	$A_s = (-C_2-(C_2^2-4*C_1*C_3)^{1/2})/2*C_1 =$	2.164	in^2/ft

Bar Size (#)	10	(enter value)
Spacing (C-C)	7	in (enter value)
Area of Steel (A_s)	2.10	in^2/ft

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